

GEOLOGIC CO₂ SEQUESTRATION POTENTIAL OF LIGNITE COAL IN THE U.S. PORTION OF THE WILLISTON BASIN

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EXECUTIVE SUMMARY

Coal-fired electric-generating power plants in western North Dakota provide electricity to North Dakota, South Dakota, Minnesota, and Wisconsin. These plants generate about 37 million short tons of CO₂ emissions annually. These power plants overlie or are proximal to enormous lignite coal deposits in the Williston Basin. This basin contains the second largest deposit of coal resources of any basin in the continental United States.

A geologic model was constructed and used to evaluate the CO₂ sequestration potential of the areas underlain by non-surface-minable lignite coal deposits in the U.S. portion of the Williston Basin. The CO₂ sequestration potential for the areas where the coal overburden thickness is 500+ ft (152+ m) is 599 million short tons (54.3 × 10¹⁰ kg). The lignite coal resources that underlie these deep areas could sequester all the annual CO₂ emissions from a 4-million-megawatt-hour-per-year electric power plant for 107 years.

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The Plains CO₂ Reduction (PCOR) Partnership is a collaborative effort of public and private sector stakeholders working toward a better understanding of the technical and economic feasibility of

capturing and storing (sequestering) anthropogenic carbon dioxide (CO₂) emissions from stationary sources in the central interior of North America. It is one of seven regional partnerships funded by the U.S. Department of Energy's (DOE's) National Energy Technology Laboratory (NETL) Regional Carbon Sequestration Partnership (RCSP) Program. The Energy & Environmental Research Center (EERC) would like to thank the following partners who provided funding, data, guidance, and/or experience to support the PCOR Partnership:

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BACKGROUND/INTRODUCTION

As one of seven Regional Carbon Sequestration Partnerships (RCSPs), the Plains CO₂ Reduction (PCOR) Partnership is working to identify cost-effective CO₂ sequestration systems for the PCOR Partnership region and, in future efforts, to facilitate and manage the demonstration and deployment of these technologies. In this phase of the project, the PCOR Partnership is characterizing the technical issues, enhancing the public's understanding of CO₂ sequestration, identifying the most promising opportunities for sequestration in the region, and detailing an action plan for the demonstration of regional CO₂ sequestration opportunities. This report provides a reconnaissance-level assessment of the geologic CO₂ sequestration potential of lignite coal deposits in the U.S. portion of the Williston Basin.

These lignite coal resources have two key attributes that warrant their evaluation as a geologic CO₂ sequestration option. First, they underlie or are located in close proximity to eight coal-fired power plants, which emit an estimated 37.3 million short tons (33.8×10^9 kg) of CO₂ annually. Second, it has been suggested that lignites could have a large capacity for CO₂ storage (Stricker and Flores, 2002).

Evaluating the geologic CO₂ sequestration potential of a coal deposit requires information about its geologic, hydrologic, compositional, and physical properties. The geologic variables that would control the CO₂ sequestration potential of a coal deposit are similar to ones that control the formation of coalbed natural gas deposits (Pashin et al., 2001).

GEOLOGIC OVERVIEW

A map of the U.S. portion of the Williston Basin is shown in Figure 1. The Williston Basin is a large, structurally symmetrical,

intracratonic basin. It has an areal extent of several hundred thousand square miles and covers parts of western North and South Dakota, eastern Montana, and southern Saskatchewan. The structural axis is located in the central part of the basin and trends northwest to southeast. The sedimentary rocks that fill the basin reach a maximum thickness of 16,000 ft (4877 m) (Flores and Keighin, 1999; Murphy and Goven, 1998a).

COAL-BEARING FORMATIONS

The Williston Basin contains the second largest deposit of coal resources of any basin in the continental United States (Nelson, 2001). The coal-bearing formations in the Williston Basin are estimated to contain over 530 billion short tons ($>4.8 \times 10^{14}$ kg) of lignite coal resources (Flores and Keighin, 1999).

The coal resources in the Williston Basin are predominantly located in Paleocene age sedimentary rocks. Different stratigraphic nomenclatures are used by various government agencies to describe the coal-bearing strata in the Williston Basin. For example, the U.S. Geological Survey refers to these strata collectively as the Fort Union Formation; the North Dakota Geological Survey refers to them collectively as the Fort Union Group; and in Saskatchewan, they are collectively referred to as the Ravenscrag Formation. Figure 2 provides a comparison of this stratigraphic nomenclature (Flores and Keighin, 1999).

The Bullion Creek Formation, in the Fort Union Group, contains the most abundant and thickest coal beds. This formation contains the Harmon-Hansen, Hagel, and Beulah-Zap coal zones. Individual coal beds are as much as 40 ft (12 m) thick. These coal zones are the main targets for mining and coalbed natural gas exploration (Stricker and Flores, 2002; Flores and Keighin, 1999; Murphy and Goven, 1998a).

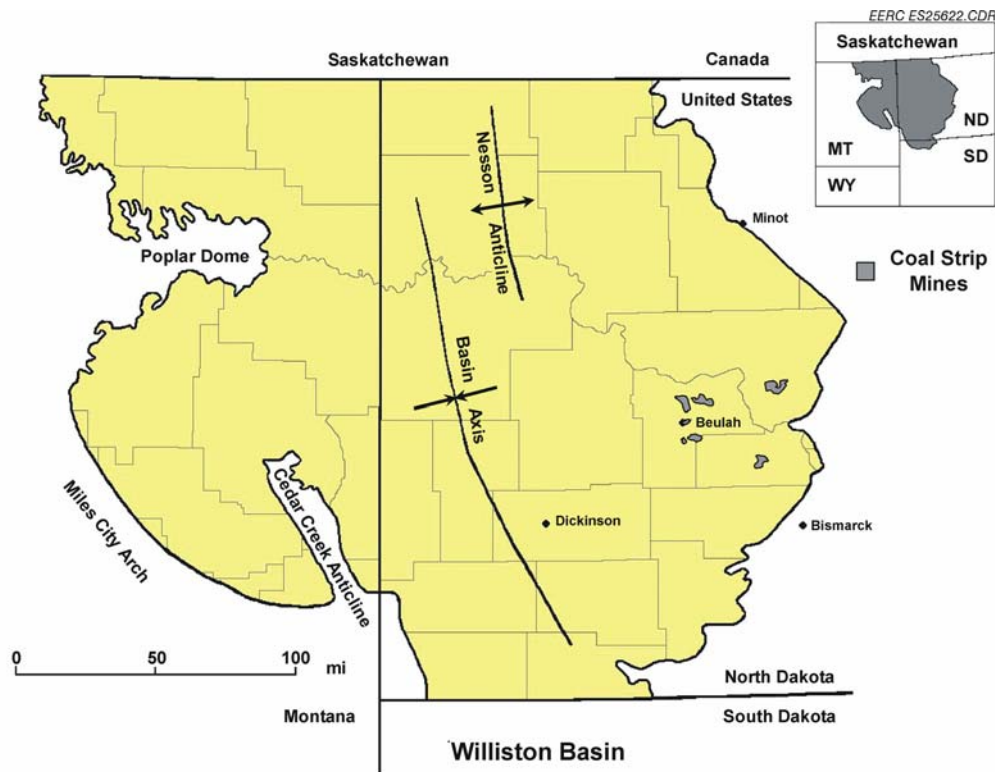


Figure 1. Map showing the location, areal extent, and major structural features of the Montana and North Dakota portions of the Williston Basin.

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Epoch	U.S. Geological Survey		North Dakota Geological Survey		Saskatchewan, Canada
Quaternary	Glacial Till Deposits		Glacial Till Deposits		Glacial Till Deposits
Eocene	Golden Valley Formation		Golden Valley Formation		
Paleocene	Fort Union Formation	Sentinel Butte Member	Fort Union Group	Sentinel Butte Formation	Ravenscrag Formation
		Tongue River Member		Bullion Creek Formation	
		Ludlow Member		Slope Formation	
		Cannonball Member		Ludlow Formation	
Upper Cretaceous	Hell Creek Formation				Frenchman Formation
	Fox Hills Sandstone				Eastend Sandstone

Figure 2. Generalized stratigraphic column showing the nomenclature in the Williston Basin.

STRATIGRAPHY

Figure 3 is a composite stratigraphic column showing the major subdivisions and coal zone locations in the Upper Cretaceous to Quaternary sedimentary rocks in the Williston Basin. The Paleocene age Fort Union Group is stratigraphically subdivided into five gross depositional units, which in ascending order are the nonmarine Ludlow, Slope, Bullion Creek, and Sentinel Butte Formations and the

regressive marine Cannonball Formation (Flores and Keighin, 1999; Murphy and Goven, 1998a; Flores et al., 1999; Murphy and Goven, 1998b, Murphy et al., 1999, Murphy et al., 2000).

The Fort Union Group ranges in thickness from 1000 to 1800 ft (305 to 550 m) in western North Dakota and contains an estimated 351 billion short tons (3.2×10^{14} kg) of lignite coal (Flores and Keighin, 1999; Murphy and Goven, 1998a).

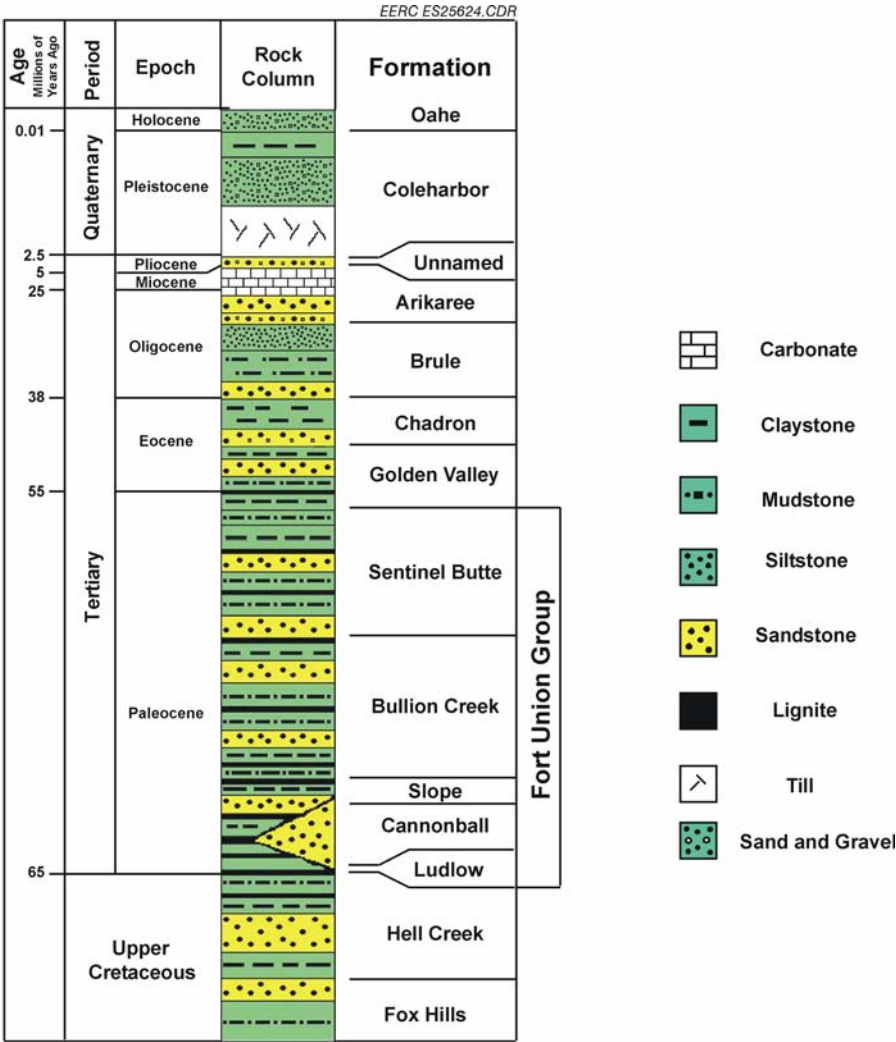


Figure 3. Composite stratigraphic column (Upper Cretaceous to Quaternary) of the North Dakota portion of the Williston Basin (modified from Murphy and Goven, 1998a).

The Golden Valley Formation contains lignite, but the lignite beds are typically thin, being generally only a few feet thick (Murphy and Goven, 1998a). The Upper Cretaceous Hell Creek Formation, which underlies the Fort Union Group, also contains thin lignite beds (Anna, 1980).

COALBED CHARACTERISTICS

Overburden thickness is a critical property that affects the suitability of a coal deposit for geologic CO₂ sequestration. Only areas where the coal seam overburden thickness is too great for economical surface or underground mining would be potential sites for geologic CO₂ sequestration (Stricker and Flores, 2002; White et al., 2003).

In the Williston Basin, 350 ft (107 m) is the maximum overburden thickness limit for surface mining of lignite coal (Stricker and Flores, 2002). The overburden thickness in most areas underlain by Fort Union Group lignite in southwestern North Dakota is typically less than 500 ft (152 m) (Murphy and Goven, 1998a,b; Murphy et al., 1999, 2000; Ellis et al., 1999).

Another critical property that affects the suitability of a coal deposit for geological CO₂ sequestration is the net coal resource within a given area. The Bullion Creek Formation contains the largest known lignite resources in southwestern North Dakota. The majority of these lignite resources are found in the Harmon and Hansen lignite beds. The lignite resources in the Harmon and Hansen beds thicker than 2.5 ft (0.8 m) are estimated to total 45 and 22 billion short tons (40.8×10^{12} kg and 20×10^{14} kg), respectively (Ellis et al., 1999).

The Harmon lignite bed, which occurs within the basal 150 ft (46 m) of the

Bullion Creek Formation, is the most areally extensive lignite bed in North Dakota. The Harmon lignite bed underlies an area of roughly 13,000 square miles in southwestern North Dakota and also extends into southeastern Montana. Throughout most of this area, the Hansen lignite bed underlies the Harmon lignite bed. Figures 4 and 5 are isopach maps showing the areal distribution, overburden thickness, and net coal thickness of the Harmon lignite bed in southwestern North Dakota (Ellis et al., 1999).

A thick, areally extensive lignite bed is also present in southern McKenzie and north-central Dunn Counties in western North Dakota. This lignite bed may be stratigraphically correlative with the Harmon lignite bed in Golden Valley and Slope Counties. The name Harmon (?) is currently used to refer to this lignite bed. The lignite resources in the Harmon (?) bed in a roughly 420-mi² (1088-km²) area of southern McKenzie County total an estimated 15.5 billion short tons (14.1×10^{12} kg) (Murphy and Goven, 1998b).

AREAS SUITABLE FOR CO₂ STORAGE

Geologic models of the Harmon, Hansen, and Harmon (?) lignite beds were created using data obtained from overburden and net coal thickness isopach maps (Murphy and Goven, 1998b; Murphy et al., 1999, 2000; Ellis et al., 1999). A minimum overburden thickness of 500 ft (152 m) was used as a screening criterion to identify areas potentially suitable for geologic CO₂ sequestration.

Equation 1 was used to calculate the coal-in-place resource for the areas suitable for geologic CO₂ sequestration. A value of 1750 tons/acre-ft (1.29 g/cm³) was used for the in situ density of the lignite coal (Ellis et al., 1999).

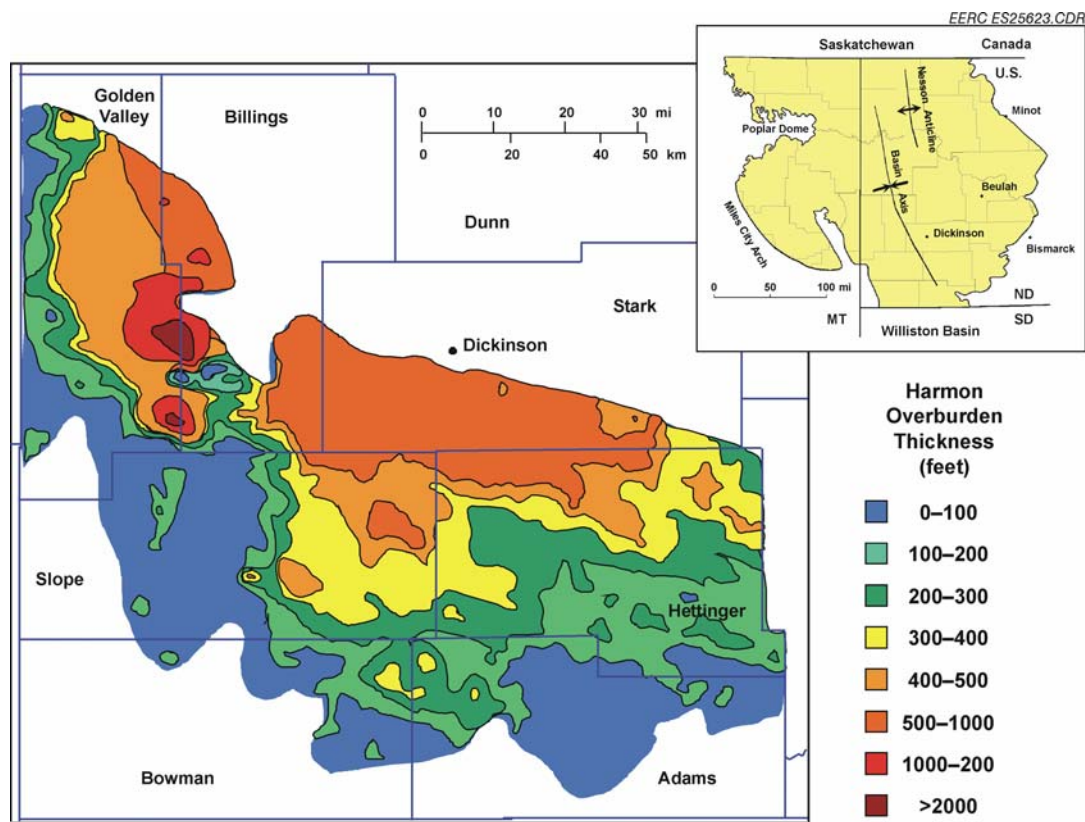


Figure 4. Net overburden thickness isopach map for the Harmon coal zone (modified from Ellis et al., 1999).

$$\text{Coal-in-Place Resource} = [A \times h \times \rho] \quad [\text{Eq. 1}]$$

where A = area (acres), h = net coal thickness (feet), and ρ = density (tons/acre-ft).

The areas where the overburden thickness of the Harmon, Hansen, and Harmon (?) lignite beds is 500+ ft (152+ m) are shown on the map in Figure 6. For the Harmon lignite bed, there is a total area of 1400-mi² (3636-km²) where the overburden thickness is 500+ ft (152+ m). Only 30% of the area underlain by the Harmon lignite (see Figure 4) has suitable overburden thickness for geologic CO₂ sequestration. In this area, the net coal thickness ranges from 2 ft (0.6 m) to 20 ft (6.1 m), and the coal resource is estimated to total 13.5 billion short tons (12.3×10^{12} kg).

For the Harmon (?) lignite bed, there is a total area of 260-mi² (673-km²) where the overburden thickness is 500+ ft (152+ m). Only 61% of the total area underlain by the Harmon (?) lignite has suitable overburden thickness for geologic CO₂ sequestration. In this area, the net coal thickness ranges from 17 ft (5.2 m) to 44 ft (13.4 m), and the coal resource is estimated to total 9.8 billion short tons (8.9×10^{12} kg).

For the Hansen lignite bed, there is a total area of 400 mi² (1036 km²) where the overburden thickness is 500+ ft (152+ m). Only 14% of the total area underlain by the Hansen lignite has suitable overburden thickness for geologic CO₂ sequestration. In this area, the net coal thickness ranges from 2.5 ft (0.8 m) to 20 ft (6.1 m), and the coal resource is estimated to total 4.2 billion short tons (3.8×10^{12} kg).

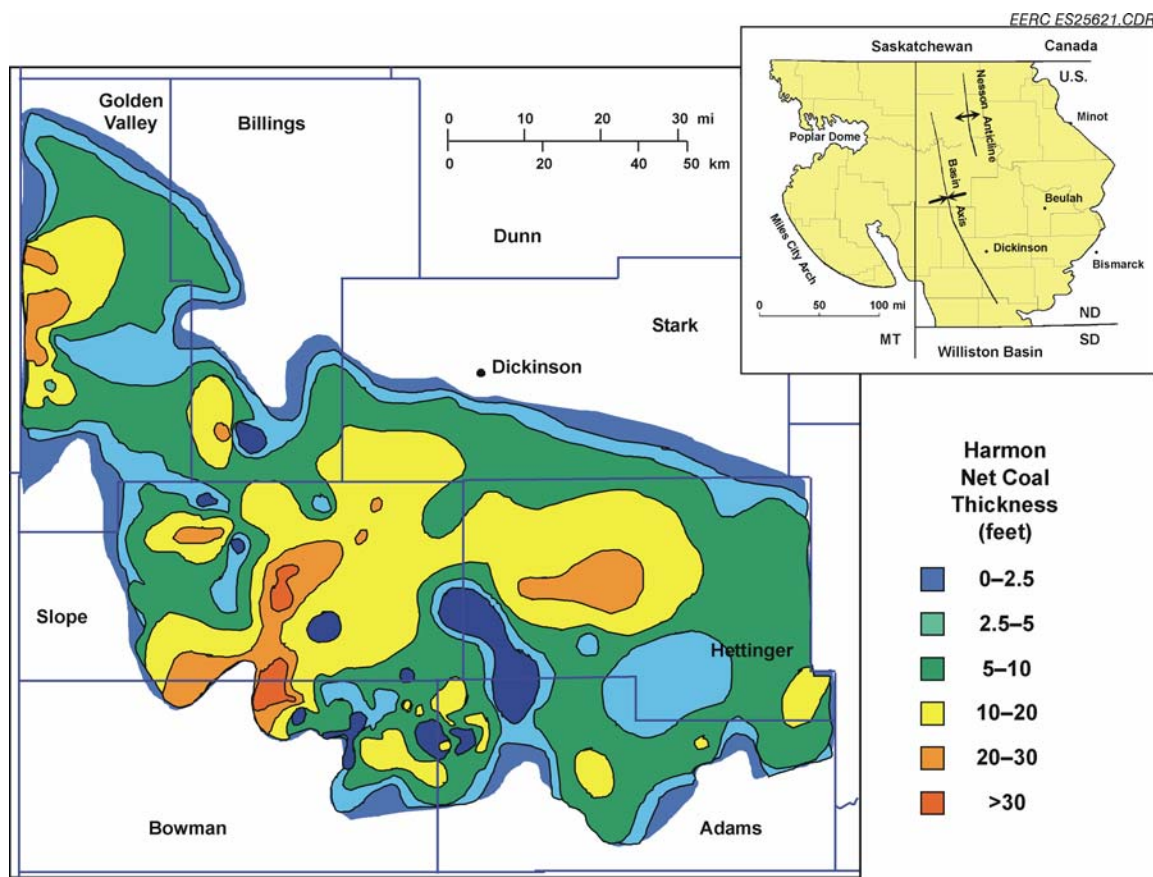


Figure 5. Net coal thickness isopach map for the Harmon coal zone (modified from Ellis et al., 1999).

COAL PRODUCTION DATA

Table 1 summarizes Williston Basin (U.S. portion) coal production, which in 2002 totaled 30.8 million short tons (27.9×10^9 kg), all of it from surface mines (see Figure 1). The Williston Basin accounted for 2.8% of U.S. coal output in 2002 (Energy Information Administration, 2002).

Table 1. Williston Basin (U.S. portion) Coal Production Data for 2002^a

State	County	Surface Mines	Coal Production, short tons
ND	McLean	1	7,622,000
	Mercer	2	18,654,000
	Oliver	1	4,523,000

^a Data from Energy Information Administration Annual Coal Report (2002).

MAJOR CO₂ EMISSION SOURCES

Eight coal-fired power plants are located within 90 miles (145 km) of the areas where the overburden and net coal thickness of the Harmon, Harmon (?), and Hansen lignite beds would be favorable for geologic CO₂ sequestration. Table 2 shows their 2001 estimated CO₂ emissions (Stricker and Flores, 2002).

GAS STORAGE MECHANISM

The sequestration of CO₂ can occur by either a physical or chemical trapping process (White et al., 2003). In coalbed reservoirs, the gas molecules are immobilized or trapped by physical

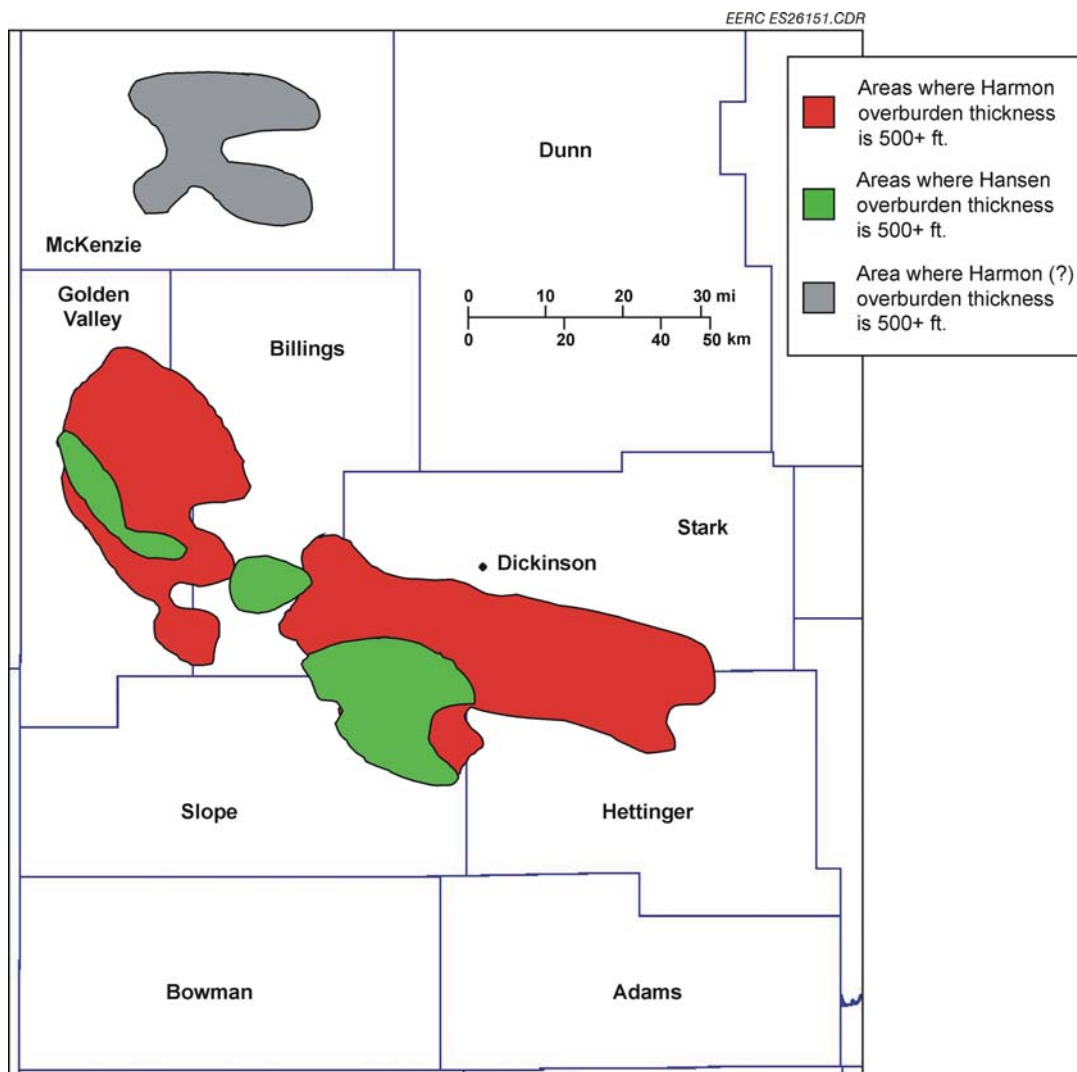


Figure 6. Map showing the areas where the overburden thickness of the Harmon, Hansen, and Harmon (?) lignite beds would be favorable for geologic CO₂ sequestration.

adsorption at near-liquidlike densities on micropore wall surfaces. In coalbed reservoirs, the hydrostatic pressure in the formation controls the gas adsorption process (Mavor and Nelson, 1997; Nelson, 1999; Pashin et al., 2001).

The gas adsorption process is reversible. Thus the hydrostatic pressure must be maintained at or above the gas desorption pressure in order for sorbed-phase gas molecules to remain immobile.

TEMPERATURE GRADIENT

Temperature affects the amount of gas that coal can adsorb. Gas sorption capacity decreases as temperature increases (Mavor and Nelson, 1997; Pashin et al., 2001; Pashin and McIntyre, 2003).

The average temperature gradient in the Fort Union Group Formation in southwestern North Dakota is 0.02°F/ft (0.019°C/m). The average ground surface

Table 2. Estimated CO₂ Emissions for Williston Basin Power Plants in 2001^a

Plant Name	Location	Estimated CO ₂ Emissions, short tons
Coal Creek	Falkirk, ND	10.67×10^6
Antelope Valley	Beulah, ND	7.94×10^6
Young	Center, ND	6.00×10^6
Leland Olds	Stanton, ND	5.85×10^6
Coyote	Beulah, ND	3.99×10^6
Stanton	Stanton, ND	1.61×10^6
Heskett	Mandan, ND	0.70×10^6
Lewis & Clark	Sidney, MT	0.53×10^6

^a Data are from Stricker and Flores (2002).

temperature is about 50°F (10°C). The relationship between temperature and depth in the Fort Union Group Formation in southwestern North Dakota is shown in Equation 2 (Anna, 1980). The estimated temperatures of the Harmon and Hansen lignite beds in southwestern North Dakota would range from about 60° to 80°F (16° to 27°C).

$$T (^{\circ}\text{F}) = 0.02 \times \text{Depth (ft)} + 50 \quad [\text{Eq. 2}]$$

CO₂ SUPERCRITICAL PHASE WINDOW

Figure 7 shows the phase diagram for CO₂. Above the critical point temperature (88°F [31°C]) and pressure (1074 psi), CO₂ is a supercritical fluid. Supercritical CO₂ may interact differently with coal than normal gaseous CO₂ (Pashin and McIntyre, 2003; White et al., 2003). Thus determining if supercritical CO₂ conditions could occur is

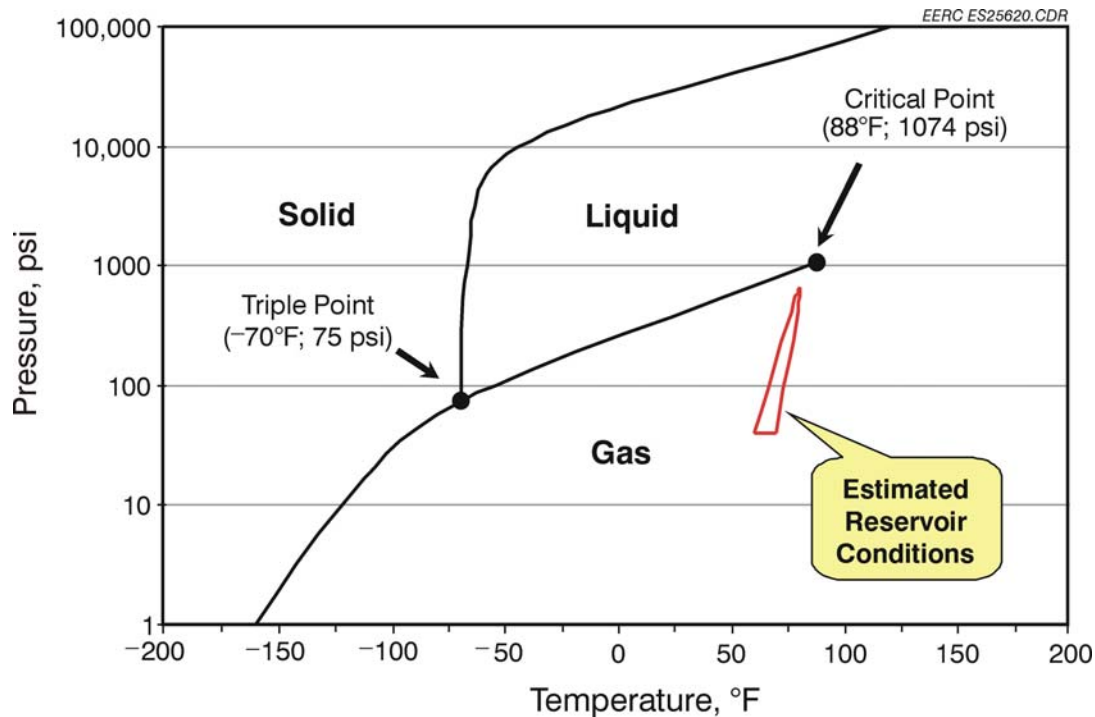


Figure 7. CO₂ phase diagram.

important when areas are evaluated for CO₂ sequestration.

Figure 7 also shows the expected range of temperature and pressure conditions in the Harmon, Harmon (?), and Hansen coal zones in southwestern North Dakota. It is expected that conditions will not favor supercritical CO₂ formation.

KEY GEOLOGIC VARIABLES

The CO₂ sequestration capacity of a coal deposit depends on five key geologic variables: 1) the amount of coal, 2) the hydrostatic pressure of the coal zone, 3) the CO₂ storage capacity of the coal, 4) the coal's content of sorbed-phase natural gas, and 5) the composition of the sorbed-phase natural gas.

The first three geologic variables define the CO₂ storage capacity of the coal deposit. The third and fourth geologic variables account for factors that would reduce the number of adsorption sites available for CO₂ uptake and storage.

Most subsurface coal deposits contain some sorbed-phase natural gas (Nelson, 2001). The sorbed-phase gas content and its composition will affect the CO₂ sequestration potential of the coal deposit.

A sixth variable is an engineering safety factor. The injected CO₂ volume must be less than the CO₂ storage capacity of the coal because the hydrologic pressure in the formation could undergo natural variation over geologically long time periods (Pashin and McIntyre, 2003).

CO₂ SEQUESTRATION POTENTIAL

The amount of CO₂ that could potentially be sequestered in the Williston Basin's Harmon, Harmon (?), and Hansen coal zones was evaluated with the procedure that is used for gas-in-place (GIP) analysis of coalbed reservoirs (Mavor and Nelson,

1997; Nelson, 1999, 2004, 2005; Nelson et al., 2005). The CO₂ sequestration potential was calculated using Equation 3.

$$\text{CO}_2 \text{ SP} = [A \times h \times \rho \times \text{SC}_{\text{CO}_2}] \quad [\text{Eq. 3}]$$

where CO₂ SP = CO₂ sequestration potential and SC_{CO₂} = CO₂ storage capacity.

The gas storage capacity calculations were made using the Langmuir isotherm model, which is a numerical model that describes the relationship between the gas storage capacity and pressure. This is the most commonly used isotherm model for coal (Mavor and Nelson, 1997).

The Langmuir isotherm model is shown in Equation 4. The gas storage capacity of coal varies nonlinearly as a function of pressure. The Langmuir volume (V_L) corresponds to the gas storage capacity at infinite pressure. The Langmuir pressure (P_L) is the pressure at which the gas storage capacity equals one-half the Langmuir volume.

$$V = [V_L \times (P / (P + P_L))] \quad [\text{Eq. 4}]$$

where V = gas storage capacity, V_L = Langmuir volume, P = pressure, and P_L = Langmuir pressure.

CO₂ storage capacity varies as a function of temperature, coal sample properties such as the moisture and mineral matter content, and the coal rank (Nelson, 2003; Carroll and Pashin, 2003). Figure 8 is a graph comparing the CO₂ storage capacities of lignite coal samples from the Williston Basin with a subbituminous coal from the Powder River Basin (Nelson, 2003). At similar temperature and moisture content conditions, the lignite samples have a much greater capacity for CO₂ storage than the subbituminous coal.

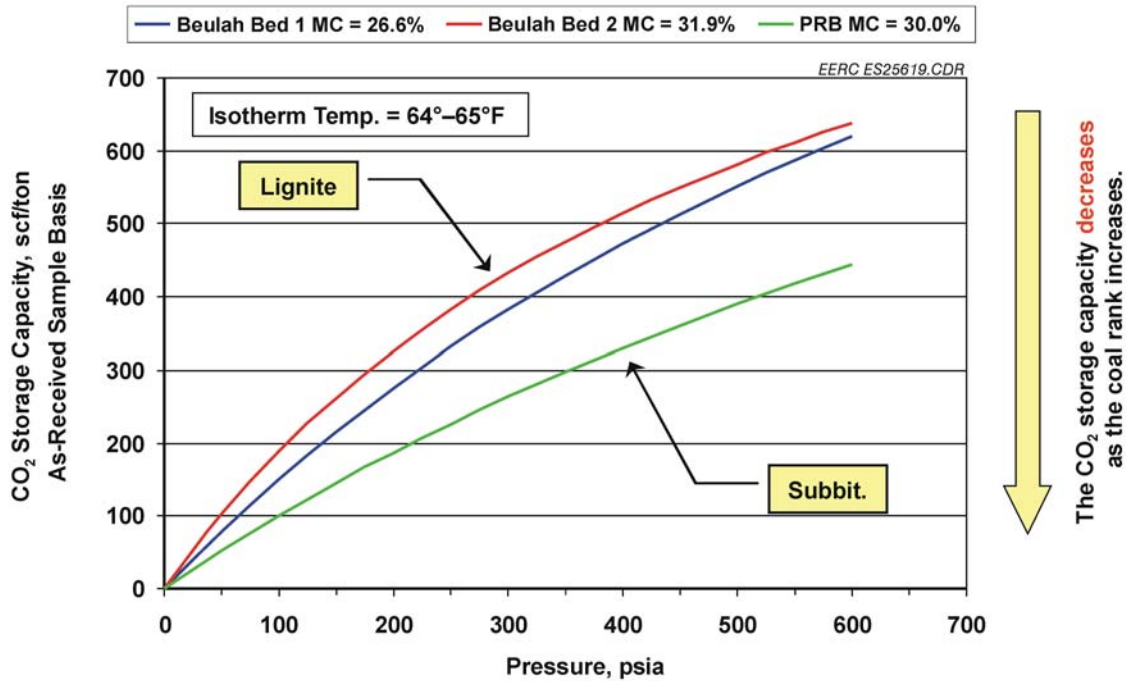


Figure 8. Comparison of CO₂ storage capacity of lignite and subbituminous coal.

The CO₂ storage capacities of the Harmon, Harmon (?), and Hansen lignite beds were estimated using Equation 5. The Langmuir volume ($V_L = 1220$ scf/ton) and pressure ($P_L = 548$ psia) are average values that were determined experimentally for lignite from the Williston Basin. The estimate of the reservoir hydrostatic pressure (P) was based on the midpoint reservoir depth and assumed a normal hydrostatic pressure gradient of 0.433 psi/ft.

$$SC_{CO_2} = [1220 \times (P/(P + 548))] \quad [\text{Eq. 5}]$$

An engineering safety factor was also included in the calculation of the CO₂ storage capacity estimate. The safety factor set the maximum sorbed-phase CO₂ volume at a value where CO₂ desorption would begin if there was a 20% reduction in the hydrostatic pressure.

An internally consistent set of coal seam thickness, density, and CO₂ storage capacity values was used for the

calculations. The coal seam thickness obtained from the isopach map shown in Figure 5 reflects the in situ bulk compositional properties of the coal. Thus in situ basis coal density and CO₂ storage capacity values were used for the calculations.

NATURAL GAS RESOURCE POTENTIAL

CO₂ emissions to the atmosphere are not currently regulated, and there is little to no market value associated with geologic CO₂ sequestration. An economically viable approach would be to sequester CO₂ in unminable coal seams in conjunction with natural gas recovery. The natural gas would provide a revenue stream to partially offset the costs of CO₂ capture and sequestration (Garduno et al., 2003; Pashin et al., 2001; White et al., 2003; Wong et al., 2000).

The Williston Basin is not an active coalbed natural gas play area. However,

various observations indicate that some natural gas is present in the Williston Basin's lignite coals. These indications include the presence of flammable gas in water wells, the presence of dissolved methane in groundwater samples, and observations of gas emission from drill cutting coal samples (Anna, 1980; Murphy and Goven, 1989a). The injection of CO₂ would be expected to enhance the recovery potential of this coalbed natural gas resource (White et al., 2003).

The natural gas resources that might potentially be present in the Williston Basin's Harmon, Harmon (?), and Hansen lignite beds were evaluated with the procedure that is used for GIP analysis of coalbed reservoirs (Mavor and Nelson, 1997; Nelson, 1999, 2004, 2005; Nelson et al., 2005). The GIP estimates were calculated using Equation 6:

$$\text{GIP} = [A \times h \times \rho \times \text{GC}] \quad [\text{Eq. 6}]$$

where GC = sorbed-phase gas content.

No reliable gas content data have been published for any lignite coals in the Williston Basin. The sorbed-phase gas content was estimated using the Langmuir isotherm model shown in Equation 7.

$$\text{GC} = [158 \times (P/(P + 1605))] \quad [\text{Eq. 7}]$$

The Langmuir volume ($V_L = 158$ scf/ton) and pressure ($P_L = 1605$ psia) are average values that were determined

experimentally for CH₄ adsorption on lignite samples from the Williston Basin.

The gas content analysis assumed that the lignite was undersaturated with respect to its maximum sorbed-phase CH₄ storage capacity. A value of 80% gas saturation was used to calculate the sorbed-phase gas content values.

Figure 9 shows the CH₄ storage capacity isotherm used for the gas content analysis. The estimate of the reservoir hydrostatic pressure (P) was based on the midpoint reservoir depth and assumed a normal hydrostatic pressure gradient of 0.433 psi/ft. In situ basis coal density and CH₄ storage capacity values were used for the GIP and sorbed-phase gas content calculations, respectively.

EVALUATION RESULTS

Table 3 shows the CO₂ sequestration potential estimates for the Williston Basin's Harmon, Harmon (?), and Hansen coal zones in southwestern North Dakota. The CO₂ sequestration potential estimates for the areas shown in Figure 6 where the coal overburden thickness is 500+ ft (152+ m) total 10.3 Tcf (599 million short tons).

Table 4 shows the natural gas resource estimates for the Harmon, Harmon (?), and Hansen lignite beds in southwestern North Dakota. The natural gas resource potential estimates for the areas shown in Figure 6 where the overburden thickness is 500+ ft (152+ m) total 0.56 Tcf.

Table 3. CO₂ Sequestration Potential Estimates for Williston Basin Lignite Coals

Seam Name	Area, mi ²	Coal Resource, 10 ⁹ short tons	Effective CO ₂ Capacity ^a	
			Tcf	10 ⁶ short tons
Harmon ^b	1400	13.5	5.5	318.6
Harmon (?) ^b	260	9.8	3.3	192.8
Hansen ^b	400	4.2	1.5	87.3
Total	NA	27.5	10.3	598.7

^a 20% pressure decrease required before start of gas desorption.

^b Estimates are for areas where the coal overburden thickness is 500+ ft (152+ m).

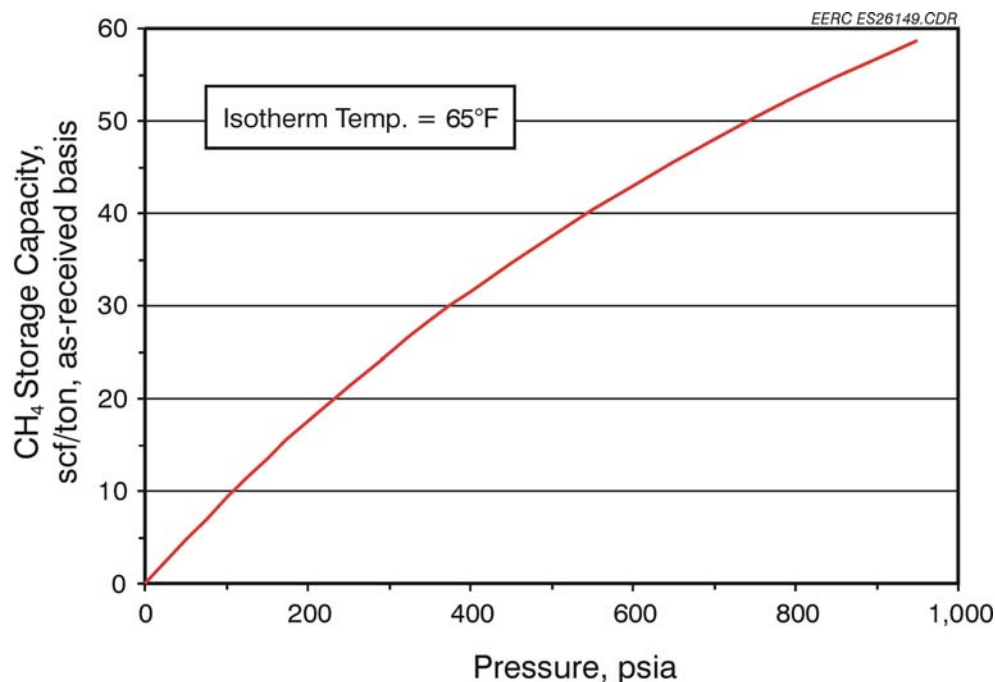


Figure 9. CH₄ storage capacity isotherm for lignite from the Williston Basin.

Table 4. Gas Resource Estimates for Williston Basin Lignite Coals

Seam Name	Area, mi ²	Natural Gas Resource ^{a,b} Tcf
Harmon	1400	0.30
Harmon (?)	260	0.18
Hansen	400	0.08
Total	NA	0.56

^a Estimates assume that the coalbed reservoirs are only 80% gas saturated.

^b Estimates are for areas where the coal overburden thickness is 500+ ft (152+ m).

SUMMARY

Coal-fired electric-generating power plants in western North Dakota generate about 37 million short tons (33.6×10^9 kg) of CO₂ annually. This CO₂ is emitted directly to the atmosphere. These power plants overlie or are proximal to enormous lignite coal deposits in the Williston Basin.

A geologic model was constructed and used to evaluate the CO₂ sequestration potential

of the areas underlain by non-surface-minable lignite coal deposits in the Williston Basin. The CO₂ sequestration potential estimate for areas where the coal overburden thickness is 500+ ft (152+ m) is 10.3 Tcf (599 million short tons). The lignite coal resources that underlie these deep areas could sequester all the annual CO₂ emissions from a 4-million-megawatt-hour-per-year power plant for 107 years.

REFERENCES

- Anna, L.O., 1980, Ground-water data for Billings, Golden Valley and Slope Counties, North Dakota: North Dakota Geological Survey Bulletin 76 – Part II, p. 241.
- Carroll, R.E., and Pashin, J.C., 2003, Relationship of sorption capacity to coal quality—CO₂ sequestration potential of coalbed methane reservoirs in the Black Warrior Basin, in 2003 International Coalbed Methane Symposium, The University of Alabama,

- Tuscaloosa, Alabama, May 5–9, 2003, Paper 0317, Proceedings: p. 11.
- Ellis, M.S., Gunther, G.L., Ochs, A.M., Keighin, C.W., Goven, G.E., Schuenemeyer, J.H., Power, H.C., Stricker, G.D., and Blake, D., 1999, Coal resources, Williston Basin, *in* 1999 resource assessment of selected tertiary coal beds and zones in the northern Rocky Mountains and Great Plains region: U.S. Geological Survey Professional Paper 1625-A, Chapter WN, p. 69.
- Energy Information Administration, 2002, Annual coal report: Office of Coal, Nuclear, Electric, and Alternate Fuels, Washington, D.C., DOE/EIA-0584, p. 68.
- Flores, R.M., Keighin, C.W., Ochs, A.M., Warwick, P.D., Bader, L.R., and Murphy, E.C., 1999, Framework geology of the Fort Union coal in the Williston Basin, *in* 1999 resource assessment of selected tertiary coal beds and zones in the northern Rocky Mountains and Great Plains Region: U.S. Geological Survey Professional Paper 1625-A, Chapter WF, p. 64.
- Flores, R.M., and Keighin, C.W., 1999, Fort Union Coal in the Williston Basin, North Dakota—a synthesis, *in* 1999 resource assessment of selected tertiary coal beds and zones in the northern Rocky Mountains and Great Plains region: U.S. Geological Survey Professional Paper 1625-A, Chapter WS, p. 44.
- Garduno, J.L., Morand, H., Saugler, L., Ayers, W.B., Jr., and McVay, D.A., 2003, CO₂ sequestration potential of Texas low-rank coals, *in* 2003 SPE Annual Technical Conference and Exhibition, Denver, Colorado, October 5–8, 2003, Paper SPE 84154, Proceedings: p. 15.
- Mavor, M.J., and Nelson, C.R., 1997, Coalbed reservoir gas-in-place analysis: Gas Research Institute Report GRI-97/0263, Chicago, Illinois, p. 144.
- Murphy, E.C. and Goven, G.E., 1998a, The coalbed methane potential of North Dakota lignites: North Dakota Geological Survey Open File Report 98-1, p. 38.
- Murphy, E.C., and Goven, G.E., 1998b, Thick coals in Dunn and southern McKenzie Counties, North Dakota: North Dakota Geological Survey Open File Report No. 93-3, p. 31.
- Murphy, E.C., Kruger, N.W., and Goven, G.E., 1999, The major coals of Bowman, Slope, Adams and Hettinger Counties, North Dakota: North Dakota Geological Survey Open File Report No. 99-1, p. 56.
- Murphy, E.C., Kruger, N.W., and Goven, G.E., 2000, The major coals of Billings, Golden Valley and Stark Counties, North Dakota: North Dakota Geological Survey Open File Report No. 00-1, p. 42.
- Nelson, C.R., 1999, Effects of coalbed reservoir property analysis methods on gas-in-place estimates, *in* 1999 SPE Eastern Regional Meeting, Charleston, West Virginia, October 20–22, 1999, Paper SPE 57443, Proceedings: p. 10.
- Nelson, C.R., 2001, North American coalbed methane resource map: GTI-01/0165, Gas Technology Institute, Des Plaines, Illinois.
- Nelson, C.R., 2003, Reservoir property analysis methods for low gas content subbituminous coals, *in* 2003 International Coalbed Methane Symposium, The University of

- Alabama, Tuscaloosa, Alabama, May 5–9, 2003, Paper 0326, Proceedings: p. 14.
- Nelson, C.R., 2004, Coalbed natural gas resource potential of subbituminous coal in the Powder River Basin, *in* 19th International Conference on Lignite, Brown, and Subbituminous Coals, Billings, Montana, October 12–14, 2004, Proceedings: p. 13.
- Nelson, C.R., Steadman, E.N., and Harju, J.A., 2005, Geologic CO₂ sequestration potential of the Wyodak-Anderson coal zone in the Powder River Basin: Energy & Environmental Research Center, University of North Dakota, Grand Forks, North Dakota, August 2005, p. 23.
- Nelson, C.R., 2005, Geologic assessment of the natural gas resources in Powder River Basin Fort Union Formation coal seams, *in* 2005 International Coalbed Methane Symposium, The University of Alabama, Tuscaloosa, Alabama, May 16–20, 2005, Paper 0506, Proceedings: p. 14.
- Pashin, J.C., Groshong, R.H., and Carroll, R.E., 2001, Carbon sequestration potential of coalbed methane reservoirs in the Black Warrior Basin—a preliminary look, *in* 2001 International Coalbed Methane Symposium, The University of Alabama, Tuscaloosa, Alabama, May 14–18, 2001, Proceedings: p. 51–62.
- Pashin, J.C., and McIntyre, M.R., 2003, Defining the supercritical phase window for CO₂ in coalbed methane reservoirs of the Black Warrior Basin—implications for CO₂ sequestration and enhanced coalbed methane recovery, *in* 2003 International Coalbed Methane Symposium, The University of Alabama, Tuscaloosa, Alabama, May 5–9, 2003, Paper 0316, Proceedings: p. 12.
- Stricker, G.D., and Flores, R.M., 2002, Potential carbon dioxide sequestration and enhanced coalbed methane production in the Powder River and Williston Basins, *in* The 28th International Technical Conference on Coal Utilization & Fuel Systems, Clearwater, Florida, March 9–13, 2002, Proceedings: p. 15.
- White, C.M., Strazisar, B.R., Granite, E.J., Hoffman, J.S., and Pennline, H.W., 2003, Separation and capture of CO₂ from large stationary sources and sequestration in geological formations—coalbeds and deep saline aquifers: J. Air & Waste Management Assoc., v. 53, p. 645–715.
- Wong, S., Gunter, W.D., and Mavor, M.J., 2000, Economics of CO₂ sequestration in coalbed methane reservoirs, *in* 2000 SPE/CERI Gas Technology Symposium, Calgary, Alberta, Canada, April 3–5, 2000, Paper SPE 59785, Proceedings: p. 631–638.



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